USAARL Report No. 90-5

Health Hazard Assessment Primer

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February 1990

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Fort Rucker, Alabama 36362-5292

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release, distribution unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 90-5	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory 6b. OFFICE SYMBOL (If applicable) SGRD-UAS	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Development Command
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 577 Fort Rucker, AL 36362-5292	7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21701-5012
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.
11 TITLE (Include Security Classification) Health Hazard Assessment Primer (U)	
12 PERSONAL AUTHOR(S) Leibrecht, Bruce C.	
13a TYPE OF REPORT 13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Year, Month, Day) 1990 February 15. PAGE COUNT 43
16 SUPPLEMENTARY NOTATION	

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	(U) health hazards, (U) materiel acquisition, (U) MANPRINT, (U) health hazards research
23	02		
24	07		

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This primer provides an introductory orientation to the Health Hazard Assessment program supporting the U.S. Army's materiel acquisition efforts. The description of types and effects of health hazards includes an inventory of those hazards commonly encountered in Army systems. Substantial text outlines the organizations and processes comprising the HHA system, along with an explanation of how the system is designed to work. A conceptual framework characterizes the steps involved in preparing a HHA report. A final section describes the program contributions made by HHA-related research and the organizations performing pertinent research. Supplemental materials include a summary of the Army's life cycle system management model, a listing of HHA points of contact, and a brief description of risk assessment codes.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Scientific Infomration Center	22b TELEPHONE (Include Area Code) 255-6907	22c. OFFICE SYMBOL SGRD-UAX-SI

DD Form 1473, JUN 86 *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

Preface

Developers of manned systems strive to field materiel which is free of significant threats to the health of operators and support personnel. In pursuing this goal, the U.S. Army has developed a program for assessing health hazards of manned systems such as combat weapons and vehicles. This document is an introductory guide to that program. It is an integration of a series of five articles which the author published in the MANPRINT Bulletin between June 1987 and January 1989. Substantive materials have been added, especially regarding the Army's materiel acquisition management model, risk assessment codes, and references.

COL J. D. LaMothe and COL Joel C. Gaydos provided invaluable comments on the separate articles. Ms. Jimmie M. Henderson typed the articles and subsequently collated them into a single document. MAJ Gary Shrum carefully reviewed drafts of the primer and made recommendations for improvement.

This primer is dedicated to the memory of COL Edward L. Buescher, whose efforts were pivotal in establishing the Army's Health Hazard Assessment Program.

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Introduction

The purpose of this primer is to provide an orientation to the U.S. Army's Health Hazard Assessment (HHA) program for materiel systems. The primer is intended primarily for new HHA Program participants, for doctrine and materiel developers, for participants in industry, and for biomedical researchers. The focus is on practical information in the context of the Army's materiel acquisition process. The goal is to make available a ready resource for individuals striving to eliminate or control health hazards in Army systems.

Background

As Army institutions go, the HHA program is a relatively "new kid on the block." Although HHA-type activities were conducted by the Army Medical Department during World War II (Gaydos, 1988), the current program's official beginnings trace back only to 1976, when questions about blast overpressure hazards surfaced in a general officer decision meeting for the Army's new 155 mm towed howitzer. Early work was conducted informally, and somewhat irregularly, by the U.S. Army Medical Research and Development Command, in alliance with the U.S. Army Human Engineering Laboratory. In 1981, The Surgeon General of the Army approved the formal establishment of the HHA program, assigning specific responsibilities to participating elements of the Army Medical Department (AMEDD). It was not until late 1983 that AR 40-10, the Army regulation governing HHA, was published. Since then the program has made great strides, providing key support to the Army's materiel acquisition efforts.

In 1985, the Army established a new program called MANPRINT, which stands for Manpower and Personnel Integration. MANPRINT emphasizes man-system integration--the incorporation of human considerations into design and development of materiel systems to ensure operability and supportability (AR 602-2). This new program places HHA under a common umbrella along with human factors engineering, systems safety, manpower, personnel, and training (Figure 1). In terms of general approach and methods used, the HHA program shares much in common with the human factors engineering and systems safety programs. The latter two have been involved intimately in HHA activities for many years and continue to play important roles. For example, safety assessment reports (SAR) routinely address health hazard issues, as did human factors engineering assessments (HFEA) until recently.

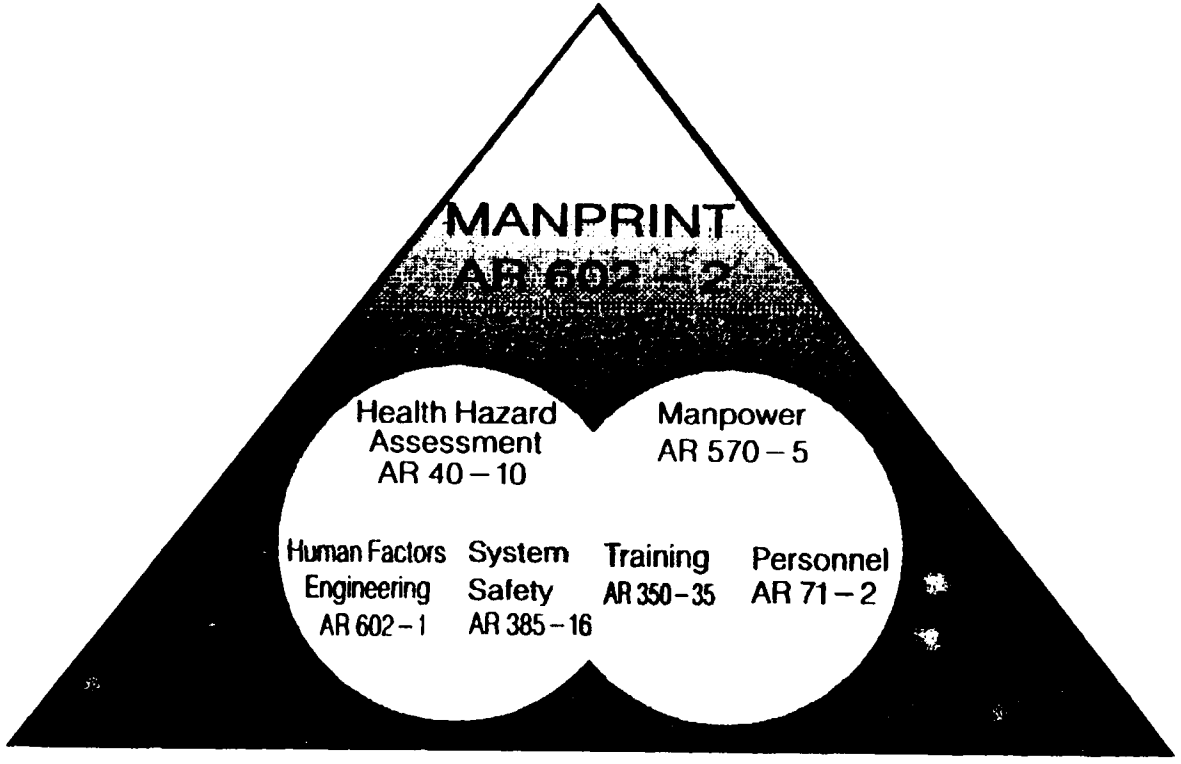

Figure 1. Diagram illustrating the six MANPRINT domains, with associated policy documents.

Definitions

A health hazard is defined as an existing or likely condition, inherent to the use of materiel, that can cause death, injury, acute or chronic illness, disability, and/or reduced job performance of personnel. Our materiel and operations are the focus, not enemy weapons, operations or local infectious diseases. The "condition" referred to in the definition can stem from system design, the environment, doctrine, biogeography, operational peculiarities, misuse, or malfunction. Notice the "can cause" scope encompasses performance aspects; the interplay between biomedical effects and performance effects can be substantive and complex.

Health hazard assessment refers to the process of identifying, evaluating, and controlling risks to the health and effectiveness of personnel who test, use, service, or support Army systems. The HHA program mobilizes resources to apply biomedical knowledge and principles in direct support of Army officials engaged in developing materiel systems. In civilian circles, HHA most closely relates to aspects of occupational health, preventive medicine, environmental medicine, and industrial hygiene/safety. However, certain fundamentals, especially the emphasis on operator-system interactions and unique aspects of military operations, give the Army's HHA program a distinctive character.

Program objectives

The overall goals of the HHA program are (1) to bolster warfighting capabilities by conserving or enhancing fighting strength, and (2) to help ensure successful Army modernization in a safe, efficient, cost-effective manner. Program objectives include: (a) preventing combat casualties and performance decrements caused by routine operation of our own combat systems; (b) enhancing soldier performance and system effectiveness; (c) reducing health-related readiness deficiencies; (d) reducing system retrofit requirements; and (e) reducing disability compensation liabilities. In terms of policy, HHA stresses key principles common to every MANPRINT domain--early and continuing involvement in system development, total system and total life cycle evaluation, and emphasis on realistic, empirical data for assessment efforts.

The nature of health hazards

Types of health hazards

A variety of health hazards can affect directly the soldier operating military systems. These hazards arise from characteristics of the system and the environment in which it operates. Chemically active substances abound in manufacturing, operating, and maintaining most systems. Normal operation of materiel systems, components, assemblies, etc. produces energy in specific forms--mechanical, electromagnetic, thermal--as well as chemical byproducts. In the operational setting, environmental aspects--most notably, temperature extremes, humidity, wind, high altitude, and biological substances--interact intimately with the system and its crewmembers. For Army purposes, these factors can be organized into five major categories, shown in Table 1. Appendix A inventories the primary health hazards associated with Army systems, differentiates basic forms, and lists generic sources.

Table 1.

Categories of health hazards.

Category	Type
Mechanical forces	Steady noise
	Impulse noise
	Blast overpressure
	Vibration
	Shock
	Trauma
Chemical substances	Liquids
	Gases
	Solids
Biological substances	Microorganisms
Radiation	Visible light
	Infrared
	Ultraviolet
	Radiofrequency energy
	Laser energy
	Ionizing radiation
Environmental extremes	Ambient heat
	Ambient cold
	Oxygen deficiency

Effects of health hazards

Exposure to one or more health hazards does not necessarily injure a soldier or make him sick. The effects of a hazardous environment depend on intensity or amplitude, duration, number of repetitions, and other aspects of the exposure. They also may depend on the physiological and psychological state of the soldier at the time of exposure. The immediate functional impact on the soldier can range widely from negligible effects to complete incapacitation, even death. However, three general functional states can be distinguished--performance limited, physiologically distressed, and incapacitated. On the less severe end of the spectrum, sensory decrements and/or minor injury characterize performance limiting effects, leaving the soldier capable of performing at a constructive level with, at most, minor medical attention. Examples of this category are minor hearing loss, mild hypoxia, and muscle strain. Moving toward more severe impacts, physiologically distressing effects compromise seriously the soldier's capability to perform his combat role; they frequently involve psychological distress and/or moderate injury, and may require substantial medical attention. Examples of this category are dizziness, moderate nausea,and severe fatigue. Incapacitating effects render the soldier nonfunctional and incapable of caring for himself or herself. Examples include carbon monoxide poisoning, combat exhaustion, and serious burns.

Many of the effects of health hazards are not immediate--they may appear only after months or years of exposure. While such effects may not rapidly impact the soldier's performance, they can limit his longterm contributions to the Army and may cause serious health problems in the future. Examples of delayed, or "chronic," effects include cancers, organ system disorders (e.g., liver damage, severe hearing loss), psychiatric disorders, birth defects, and genetic mutations.

The HHA system

Participating organizations

Three components of the AMEDD exercise major roles in implementing the HHA program: the Office of The Surgeon General (OTSG), the U.S. Army Health Services Command (HSC), and the U.S. Army Medical Research and Development Command (MRDC). To implement TSG's Army Staff responsibilities, OTSG establishes HHA policy and provides central coordination of the HHA program. The latter is accomplished by the Health Hazard Assessment Coordinator, who works in the Preventive and Military Medicine Consultants Division of the Professional Services Directorate, part of the U.S. Army Health Professional Support Agency. HSC, as the operational health services provider for the Army, has primary responsibility for providing direct HHA support. Within HSC, the Academy of Health Sciences (AHS) reviews requirements documents and provides medical input to them, while the U.S. Army Environmental Hygiene Agency (AEHA) normally performs HHAs. At installation Medical Department Activities (MEDDAC) and Medical Centers (MEDCEN), preventive medicine personnel provide local support at the working group level. Finally, MRDC conducts biomedical research in support of HHA requirements and assists in conducting HHAs.

In addition to the AMEDD organizations mentioned above, the HHA program depends critically on nonmedical elements for successful implementation. The nonmedical participants include key Army General Staff agencies (especially the Office of the Deputy Chief of Staff for Personnel--ODCSPER), the U.S. Army Training and Doctrine Command (TRADOC), the U.S. Army Materiel Command -- AMC (including the Human Engineering Laboratory--HEL, and elements of the Test and Evaluation Command--TECOM), the Combat Systems Test Activity (CSTA), the Operational Test and Evaluation Agency (OTEA), program executive officers (PEO), project and product managers (PM), the Army's systems safety community, and specialists in industry. As with the other domains of MANPRINT, then, HHA is clearly a teamwork affair.

Requirements documents review process

Medical input to development of a new system begins with review of the system's requirements documents. These documents define and validate the need for the system and outline its essential operating characteristics. The combat developer (CBTDEV--usually the TRADOC proponent) or the materiel developer (MATDEV--the program, project, or product manager), as appropriate, submits draft system requirements documents to the AHS for official review and input. Focusing on identification of potential health hazards and applicable health standards, the

Academy's Combat Developments Directorate prepares comments and sends them back directly to the requesting developer. In practice, unofficial input or advice may be obtained from AEHA or MRDC.

The HHA process

By regulation, a HHA is required for each materiel system, component, item, and product improvement, including nondevelopmental items. The primary mechanism for accomplishing a HHA is the HHA report (HHAR). This document provides a standard structure and approach for assessing systems-generated threats to the health of crewmembers, maintainers, trainers, and other troops. The system involved in generating a HHAR is represented in Figure 2.

The MATDEV is responsible for developing the best system he can, free of as many health hazards as possible. To that end, he is required to submit, through command channels to OTSG, a written request for a HHAR. The CBTDEV also may request a HHAR, usually in conjunction with user testing. Along with the request goes descriptive information on the system and how it will be used and, importantly, any test results related to health hazard issues. As the request proceeds through channels, key waystations are the Command Surgeon's Offices in AMC and/or TRADOC. AMC Headquarters maintains a HHA officer who coordinates AMC's HHA actions, while the TRADOC Surgeon's Office includes a health standards officer who reviews and tracks HHA activities. When the request reaches OTSG, the HHA Coordinator designates an independent medical assessor--normally AEHA, but occasionally MRDC--to prepare a draft HHAR. (Actual preparation of the HHAR is discussed in a later section.) When ready, the draft HHAR is submitted to OTSG for review and final coordination. After finalizing the HHAR, OTSG approves the document and forwards it through channels to the requesting developer.

What happens after the developer receives the approved HHAR is perhaps the most important part of the HHA process. The resolution of identified health hazard problems--follow-through--yields the real payoff to the Army. The MATDEV incorporates health hazard issues and concerns into milestone decision documents, while the CBTDEV provides the user position on the acceptability of health risks. The formal materiel acquisition decision body (i.e., Defense Acquisition Board, Army Systems Acquisition Review Council or In-Process Review) is responsible for verifying that a proper HHAR is completed and that appropriate action is taken to resolve health hazard issues. In implementing the HHAR's recommendations, the MATDEV takes corrective actions to eliminate, reduce, or control health risks before systems are fielded. If health protection criteria are

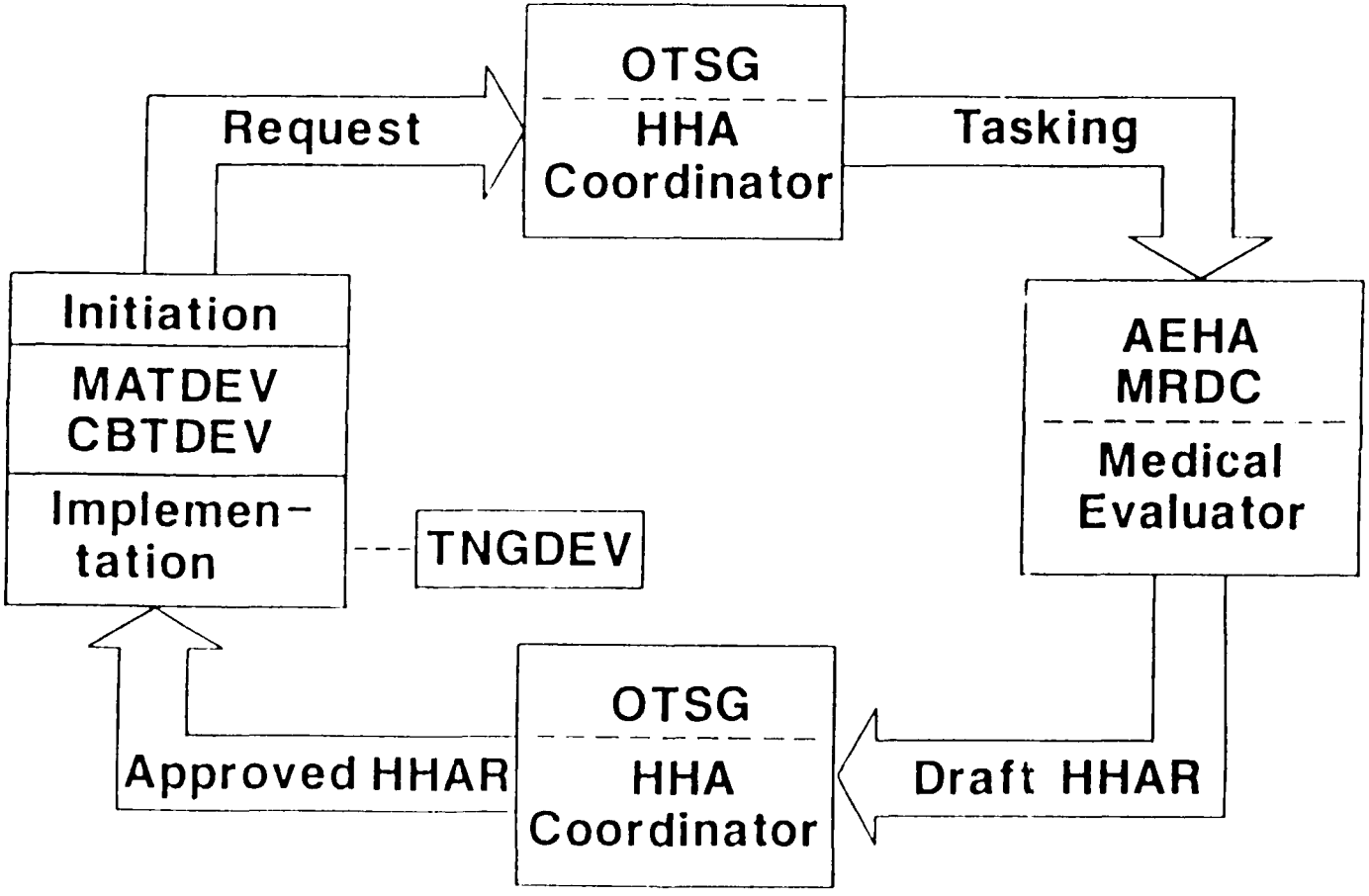

Figure 2. Schematic representing the system involved in generating a HHAR.

compromised in the materiel acquisition decision process, the MATDEV must document formally the risks accepted. It is essential procedures adopted to control health risks be incorporated in technical and training pubications and materials (by the combat, materiel, and training developers).

How the system works

HHA across the acquisition cycle

As with the other MANPRINT domains, HHA activities are integrated throughout all phases of a system's development and acquisition cycle. The basic cycle is illustrated in Appendix B. During the program initiation phase (Mission Area Analysis), the CBTDEV incorporates health hazard considerations and criteria in the requirements document (Operational and Organizational Plan, Mission Need Statement, Training Device Need Statement), based on input from the AHS and other AMEDD elements. Responsibilities and tasks needed to control potential health hazards are identified in the System MANPRINT Management Plan (SMMP) prepared by the MANPRINT Joint Working Group (MJWG), which includes medical representatives typically from a MEDDAC/MEDCEN.

In the concept exploration/definition phase, the CBTDEV and MATDEV ensure HHA requirements are included in program management documents, especially the Test and Evaluation Master Plan (TEMP), the Integrated Logistics Support Plan (ILSP), and the Acquisition Plan. They also obtain a HHAR from OTSG, submitting test and evaluation data related to health hazards for evaluation, if available. Medical representatives on the MJWG help update the SMMP. The MATDEV incorporates HHA requirements in the request for proposal (RFP), based on AMEDD input. Responsible organizations obtain medical input to the System Safety Program Plan (SSPP), SAR, and related safety documents. OTSG, AEHA, MRDC, and MEDDACs/MEDCENs provide health hazard consultation as required.

During concept demonstration/validation, the formal requirements document (Required Operational Capability--ROC, or Training Device Requirement--TDR) specifically addresses health hazard considerations peculiar to the system. Medical personnel input HHA requirements to the RFP for this phase. The CBTDEV, MATDEV, and independent evaluator collect health hazard data, which form the basis for an updated HHAR. In turn, the updated HHAR provides irput to the updated TEMP, SMMP, SSPP, and safety documents. Actions to control health hazards are implemented by the MATDEV. AMEDD elements continue to furnish health hazard consultation, including direct test support when required in special cases.

In the full-scale development phase, testers collect data

required to address unresolved health hazard issues. To determine the system's status in terms of health risks, the MATDEV obtains an updated HHAR from OTSG. The results of this evaluation are incorporated in the updated SMMP and safety documents. Contract specifications are developed and refined to ensure health hazard requirements are met. The MATDEV implements corrective actions required to control remaining health risks, and documents management decisions to accept risks compromising health protection criteria.

As the system enters production and deployment, health hazard control procedures adopted as a result of HHAR recommendations are incorporated into technical publications and training materials. Where health hazard issues remain unresolved, testers collect required data during postproduction testing (e.g., follow-on operational test and evaluation) and submit them to the AMEDD for review. Production testing yields data documenting system conforming with HHA-related contract specifications. The MATDEV ensures engineering change proposals (ECP) receive proper review for health hazard implications. Decisions resolving remaining health hazard issues are documented and implemented.

HHA services available

MATDEVs, CBTDEVs, training developers, testers, independent evaluators, logistics support developers, users, and others can obtain a variety of HHA services. Table 2 summarizes these services and the AMEDD organizations involved in providing them.

Table 2.

Health hazard assessment services.

Service	Provider	Support organizations
Consultation	OTSG, AHS, AEHA, MRDC, MEDDAC/MEDCEN	---
Requirements document review	AHS	AEHA, MRDC
Program document review	OTSG	AEHA, MRDC
Working group representation	OTSG	AEHA, MRDC MEDDAC/MEDCEN
Safety release approval	OTSG	MRDC,AEHA, TRADOC Surgeon
Human volunteer approval	OTSG	MRDC
Data collection/analysis	OTSG	MRDC, AEHA
HHAR	OTSG	AEHA, MRDC
Special studies	OTSG	MRDC, AEHA

To obtain the HHA services listed above, contact the appropriate office from the list in Appendix C. ODCSPER updates periodically a list of MANPRINT participants which can be obtained by writing: MANPRINT Points of Contact, HQDA (DAPE-MR), Washington, DC 20310-0300.

Preparing a health hazard assessment report

To accommodate the lack of empirical data characteristic of a system's early development, AR 40-10 defines two types of HHARs. The Initial HHAR (IHHAR) comes into play during the concept exploration and early demonstration/validation phases. This report addresses health hazards generically, identifying potential hazards and pertinent health standards based on fairly gross information about the system. During later phases of development, as system prototypes and actual test data emerge, the regular HHAR provides a reasonably definitive accounting of actual or prospective hazards. In the IHHAR, recommended actions tend to focus on future data requirements, while recommendations in the HHAR typically specify corrective or precautionary actions. The flexibility afforded by the IHHAR enables early involvement in the development cycle, a cardinal principle in the MANPRINT program.

Format

The HHAR embodies a standardized, systematic methodology for evaluating the health risks of materiel systems. By providing a specified structure and common elements of information, the HHAR helps ensure comprehensive medical input consistent across the spectrum of Army systems. AR 40-10 defines the standard format for the HHAR (Table 3), which is designed to document clearly the logical process by which recommended actions are developed.

Ingredients

What key ingredients are essential in preparing a HHAR? In general terms, two types of information must be available--descriptive and quantitative information about the system itself, and health standards against which to judge the health-threatening characteristics of the system. Descriptive information should include a comprehensive accounting of components, subsystems, special materials, simulators and other training devices, special support and maintenance equipment, and special salvage or disposal equipment. Also important is a complete description of how the system will be employed--operating/train-

Table 3.

HHAR format.

Paragraph		Contents
1.	References	Listing of source materials
2.	Summary	Executive overview
3.	Background	System description, predecessor system, usage scenario(s), prior assessments
4.	Identification of issues	Component-based inventory of potential/actual hazards
5.	Assessment of issues	Data analysis and conclusions vis-a-vis health standards
6.	Recommendations	Recommended actions for hazard control, with risk assessment codes
7.	Preparer	Preparing organization, POC, date prepared

ing doctrine, logistics support concepts (including all levels of maintenance), salvage/ disposal concepts, NBC requirements, and environmental conditions expected to be encountered. Obviously, considering the complete life cycle of the system is imperative.

Quantitative information about the system will include hazard-related data (e.g., noise and vibration signatures) from technical testing, user testing, special hazard evaluations, previous health hazard assessments, mishap reports, safety incidents, and sometimes modelling efforts. In the case of an IHHAR, only data from a predecessor system may be available, if data are available at all. In the absence of quantitative data, definitive statements about levels of risk are impossible.

Health standards provide the yardsticks with which to gage the severity of quantified hazards. These standards can take several forms--medical exposure limits, health conservation standards, and materiel design standards. Usually they are published Army documents (medical technical bulletins, military standards, military specifications, Army regulations), but occasionally they are national standards (e.g., Occupational Safety and Health Administration, American National Standards Institute) or international standards (e.g., International Standards Organization). Rules, both formal and informal, for applying these standards are necessary to ensure relevance and

consistency. Though often not available, comprehensive biomedical databases are very helpful in gaging real levels of risk, especially when quantified hazards exceed established limits.

Preparation steps

Once the necessary ingredients are on hand, what steps does a medical assessor follow in developing a HHAR? Depicted in Figure 3 is an idealized sequence of steps characterizing the preparation process.

System analysis and hazard identification

The foundation of the HHAR process is the careful analysis of the physical system and the doctrine for its utilization in order to identify potential health hazards. All components and subsystems; all phases of the system's life cycle (manufacturing, fielding, shipping, operational use, repair, salvage, and eventual disposal); all personnel who will interact with the system (operators, passengers, nearby troops, maintainers, logistics support personnel, trainers); special operating conditions (e.g., NBC operations, river crossing, airdrop); anticipated environmental conditions (night, rain, desert, tropics, arctic, high altitude)--all provide important clues or contributing factors regarding potential health hazards. Components which generate microwaves, vibration, or toxic fumes, for example, usually are obvious health hazard indicators; less obvious may be heat build-up during NBC operations or infrared radiation from light sources. From the system-based analysis comes a comprehensive inventory of hazardous entities which could reasonably be expected to place personnel at risk.

Data analysis

For each hazard inventoried, the medical assessor next analyzes the quantitative data available. The quality, completeness, and validity (conforming with operational concepts) of the data are determined first; serious deficiencies prompt recommendations for future data collection. Raw or intermediate data may need to be reduced, converted to different units of measure, or reorganized to be suitable for interpretation. Those data adequate for interpretation are compared to pertinent health standards to ascertain whether the quantified levels are acceptable, given the frequency and duration of exposure expected from relevant scenarios (training, maintenance, resupply, disposal, etc.). Where appropriate, the effects of required or available protective equipment (e.g., helmets, hearing

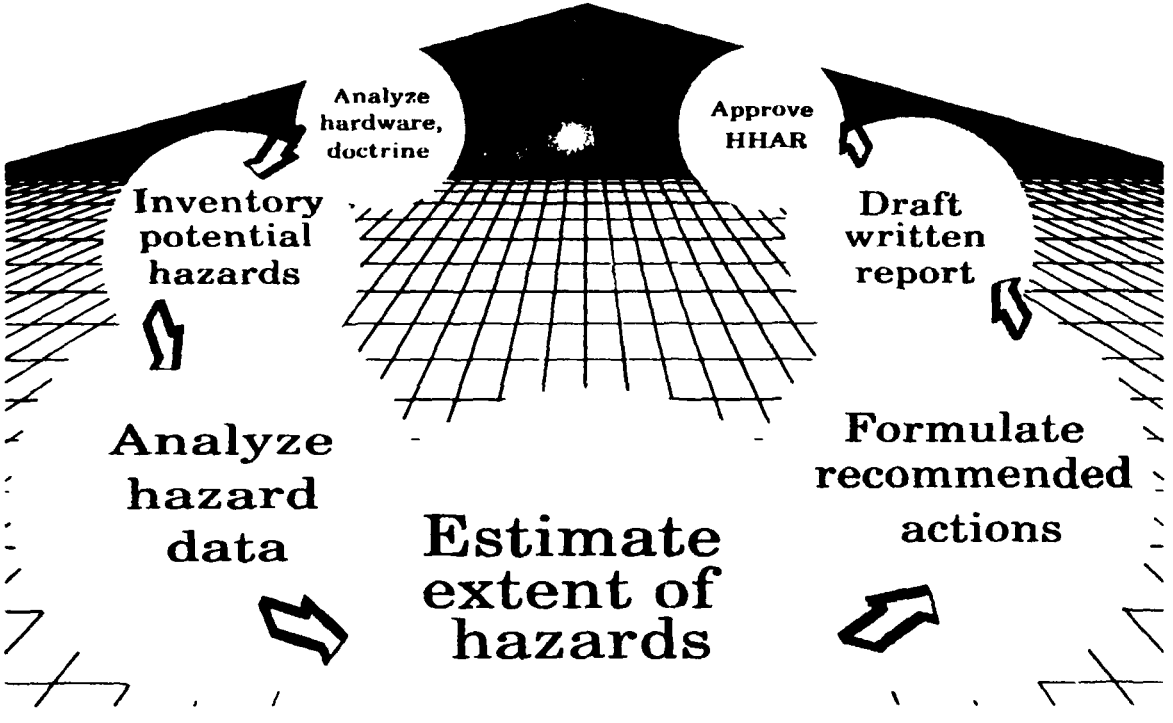

Figure 3. Illustration of the sequence of steps involved in preparing a HHAR.

protectors) must be accounted for in determining effective exposure profiles.

Risk assessment

The next step is to estimate the degree of risk associated with each hazard by assigning a risk assessment code (RAC). The RAC (Appendix D) is an index of a hazard's criticality and is useful in establishing priorities for control actions. Two factors determine the actual RAC--hazard severity and hazard probability. Reflecting the worst potential consequence, hazard severity is defined in terms of degree of injury or occupational illness which could result. Categories of severity include: negligible (less than minor), marginal (minor), critical (severe), and catastrophic (death). Hazard probability reflects the likelihood of occurrence, ranging from improbable to frequent. The RAC integrates both hazard severity and probability to yield a number between 1 and 5, with 1 reflecting the highest degree of risk.

Development of recommendations

Based on the analysis of each hazard, the medical assessor next formulates recommended actions to reduce, control, or eliminate hazards posing unacceptable degrees of risk. The types of control options available appear in Table 4.

Effective design features during early system development are obviously the most desirable of all options, but redesigning or retrofitting the system may be necessary to reduce the intensity or level of hazards at crew locations. Engineering measures may focus on hazard source, transmission routes, or active crew station conditioning options.

Protective devices are primarily systems worn by individuals to protect the head, eyes, ears, or face (e.g., helmets, laser protective goggles), other portions of the body (e.g., protective clothing or gloves), and the respiratory tract. They also may regulate body temperature (e.g., cooling vests, cold weather clothing). Most protective systems are passive, but they may operate actively, as in the case of cooling vests and active hearing protectors.

Administrative controls usually are geared around the soldier's medical or physiological state. Personnel selection criteria might exclude soldiers already exhibiting substantial hearing loss from operating a very noisy system. Examples of occupational health monitoring procedures are periodic audiometric testing and radiation film badges. Environmental

Table 4.

Health hazard control options.

Type	Option
Engineering controls	Source modification Materials substitution Containment/isolation/ shielding Environmental conditioning/filtering/ ventilation
Protective equipment	Trauma/burn protection Respiratory protection Sensory protection Body temperature protection
Administrative controls	Personnel selection/retention criteria Occupational health monitoring Environmental criteria
Operating controls	Training/conditioning/ adaptation Operating cycle/timing Crew positioning System configuration and mode

criteria might take the form of limiting training during very hot climatic conditions.

Operating controls encompass limitations on operating cycle (duration or frequency), crew locations or posturing (consider crouched mortarmen), operating mode (e.g., vehicle speed), and system configuration (e.g., tank hatches closed). Training in safe operations, to include use of protective devices, is typically an important consideration. Physical conditioning or environmental adaptation also may be appropriate to consider.

For each hazard exceeding established exposure standards, there should be one or more control measures recommended. Selection of control options must be tailored to the specific system and its operational requirements. Hazard controls may be

needed for maintenance and support personnel as well as crewmembers and passengers. More than one type of control option may be necessary for some hazards. Likewise, both short-term and long-term measures may be necessitated by practical considerations. If the analysis of data revealed deficiencies in available data, the recommendations also should include requirements for additional data collection.

Report finalization

By the time recommended actions have been formulated, the bulk of the work on the HHAR is done. The major effort remaining is to commit the results of the foregoing steps to paper, using the prescribed format. This may involve merging inputs from multiple organizational elements sharing the task of preparing the HHAR. The final step in completing the HHAR consists of staffing and approval by OTSG. When the latter step is finished, the HHAR is ready for delivery to the requesting office.

Research supporting health hazard assessment

Research roles

Though often operating "behind the scenes," research plays three major roles in the HHA program: developing new tools, conducting special studies, and performing medically related test and evaluation.

Developing new tools

Routine functioning of the HHA program relies on key tools which include biomedical databases, methods for evaluating materiel, health standards, methods for evaluating protection, prediction models, improved protection, and troop health indicators (see Table 5). For a given health hazard, some or even all of these tools may be deficient or lacking. For example, the existing health standard for impulse noise is based on a very limited data-base and has never been validated (Leibrecht and Patterson, 1986). Forward looking research serves to develop new or improved tools in order to advance HHA capabilities. Such research usually consists of laboratory investigations (using both animals and humans), technology or methodology development, and mathematical modeling. It also may involve field evaluations (more often with humans, but occasionally with animals) and epidemiology. To reach maturity, these types of research normally require multiphase programs, substantive resources, and

long-term commitment. Thus, they depend on formal planning, programming, and budgeting to provide a stable funding environment.

Table 5.

HHA tools.

Type	Description
Health standards	Documents (e. g., noise exposure limits) specifying conditions of acceptable risk for individual hazards.
Biomedical databases	Systematic collections of empirical data on basic bioeffects, exposure-injury relationships, mechanisms of injury, and material characteristics.
Prediction models	Mathematical or analog models for predicting extent of injury based on quantitative exposure characteristics.
Protection technology	Systems, components, and subsystems for reducing effective exposure to acceptable levels, given unacceptable source levels.
Methodology for:	Equipment, facilities, and procedures for:
a) Protection device evaluation	Measuring effectiveness of protective systems.
b) Hazard measurement	Quantifying health hazard characteristics of material
c) Health monitoring	Assessing key health characteristics of personnel.

Special studies

What happens when existing tools prove inadequate to address current questions, yet system-specific answers are needed before new tools will be available? Biomedical research can step in with special studies in the form of laboratory investigations and direct hazard assessments. A system-specific laboratory investigation harnesses an actual or simulated system or component to determine its hazardous effects in the laboratory, usually using animal models. For example, a new type of millimeter wave generator could function as an exposure source to assess possible effects on the ocular lens of an appropriate animal model. In contrast, direct hazard assessment involves the study of soldiers and actual weapons exposures in the field. As a classic example of direct hazard assessment, consider the case of the M198 towed howitzer. When the developmental system exceeded impulse noise exposure limits in 1976, the AMEDD developed a special procedure to determine the adequacy of available hearing protection. Investigators exposed volunteer troops to actual howitzer firings, monitoring hearing as noise intensity increased (Patterson et al., 1985). However, the direct hazard assessment is a court of last resort because it answers only narrow questions, is very resource intensive, and takes excessive time to plan, coordinate, and execute.

Another type of special study is the health survey. Most typically an epidemiological "snapshot" of some troop population, the health survey captures data on the status of selected health indicators, such as hearing ability. For example, in the early 1970s medical investigators conducted extensive surveys of the frequency and severity of hearing loss among infantry, armor, artillery, and other troops (Walden et al., 1975). As with those surveys, the general methodology usually involves measurements on soldiers in the field, though it can involve reviewing health records or computerized databases (such as the Aviation Epidemiology Data Register). The results of health surveys provide valuable information about how well the HHA program is working as well as baseline data against which to gage future weapons effects and protective technology. The results also can influence health policy issues, including selection and retention standards.

Test and evaluation

The final category of health hazard research is medically related test and evaluation (T&E). Here the focus is on measuring pertinent characteristics of two types of materiel--systems/components which generate health hazards, and systems/components which protect against health hazards. In the first case, nonmedical T&E organizations normally collect health hazard

data for subsequent review by a medical organization. However, on occasion an AMEDD organization collects data using special instrumentation or data analysis capabilities. For example, such is frequently the case when it comes to toxic substances and vibration hazards (e.g., Butler and Maday, 1986). In discerning how well a protective system actually protects personnel, an evaluator (Government and/or contractor) performs standard measurements to quantify hazard reduction. As an excellent example of this, consider the routine evaluation of helmets for impact and noise attenuation efficacy (e.g., Mozo et al., 1988). Such evaluation occurs during prototype development, first article and initial production, and routine production (i.e., quality assurance testing).

Research organizations

By regulation, TSG is responsible for the primary health hazard research mission. In reality, MRDC--a field operating agency of TSG--performs health hazard research as part of its larger medical research and development programs. OTSG staff establishes health hazard research requirements, prioritizes them, and makes technical input to specific objectives. MRDC plans, programs, and budgets for recognized research efforts, generally by problem area. Five of MRDC's laboratories participate in executing the health hazard research program (Lam and Grubbs, 1987): U.S. Army Aeromedical Research Laboratory (USAARL); Walter Reed Army Institute of Research (WRAIR); U.S. Army Biomedical Research and Development Laboratory (USABRDL); Letterman Army Institute of Research (LAIR); and U.S. Army Research Institute of Environmental Medicine (USARIEM). Table 6 shows the general areas in which each laboratory conducts health hazard research.

While the organizations mentioned above account for the primary health hazard research programs, several other organizations participate also. AEHA has limited T&E capabilities and contributes to proposed health standards. The U.S. Army Medical Materiel Development Activity (USAMMDA) assists in the development of medically-oriented protective devices, such as ballistic/laser protective spectacles. HEL conducts some research related to health hazards, including impulse noise injury and carbon monoxide poisoning. The Product Manager (PM) for Clothing and Individual Equipment and the PM for Aviation Life Support Equipment develop protective systems such as helmets, protective clothing, and laser protection. Also playing a role are AMC's Research, Development, and Engineering Centers (RDEC), such as Natick RDEC (NRDEC) and Chemical RDEC (CRDEC), which develop new technology for helmets, microclimate cooling systems, and other clothing and protective systems. Finally, TECOM, CSTA, and OTEA all collect health hazard data on developmental systems.

Table 6.

MRDC health hazard research laboratories.

USAARL	WRAIR	USABRDL	LAIR	USARIEM
BOP*	BOP*	Smokes	Lasers	Heat
Noise	Microwaves	Obscurants	Light	Cold
Vibration	MM-waves	Combustion		Overexertion
Shock		products		Altitude
Thermal stress		Toxic effluents		
O_2 deficit				

* Note: BOP = Blast overpressure

Establishing research requirements

Ideally, the Army's long range planning process should indicate health hazard research needs alongside appropriate deficiencies and requirements identified in key planning documents such as the Battlefield Development Plan. Incorporating health hazard research requirements in these planning documents demands close coordination between planning agencies (especially TRADOC), MRDC, and OTSG. In practice, requirements more typically result from formal or informal dialog between a combat or materiel developer and an element of the AMEDD. As the MANPRINT program matures, we should expect to see MANPRINT Joint Working Groups documenting health hazard research requirements in SMMPs. In reality, combat developers, system developers, technology developers, T&E personnel, human factors and system safety personnel--all should notify OTSG when potential health hazard research requirements come to their attention. The important thing is to identify and plan for such requirements as early in a system's life cycle as possible.

Conclusions

Early and continuing review of system/subsystem/component health hazards is essential to successful materiel design and development efforts. Effective medical input and evaluation is imperative to ensure threats to troop health are eliminated or minimized. The Army's HHA program provides the resources, tools, and procedures to properly address systems health hazards. In supporting the full spectrum of a system's life cycle, a variety of HHA services is available.

As a major mechanism for effectively integrating human considerations into materiel acquisition, HHA is a key component of the MANPRINT program. To be optimally effective, HHA efforts should be conducted in concert with other MANPRINT activities. There must be careful coordination and interaction between HHA activities and efforts of the other MANPRINT domains to ensure cohesive, comprehensive, and efficient program coverage. The MANPRINT Joint Working Group forms the primary body for integrating HHA with other MANPRINT domains.

Through membership in the MANPRINT team, the HHA community shares important responsibilities in the Army's modernization efforts. Applying biomedical knowledge and principles to field safer, more effective combat systems yields invaluable payoff. The ultimate benefits--protecting the health of troops, enhancing system effectiveness and conserving warfighting assets--translate into improved combat readiness for the entire Army.

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Glossary

Combat developer (CBTDEV): Command or organization responsible for formulating fighting doctrine, materiel requirements, and organizational concepts.

Concept demonstration/validation: Normally the second phase in the materiel acquisition process. Includes steps to resolve logistics problems identified earlier, verify preliminary design and engineering, fully analyze trade-off proposals, and prepare for full scale development.

Concept exploration/definition: Initial phase of the materiel acquisition process. Includes development of acquisition strategy, evaluation of system alternatives, refinement of requirements document, and preparation for concept demonstration/validation.

Full scale development (FSD): Normally the third phase in the materiel acquisition process during which a system, including all items necessary for its support, is fully developed, engineered, fabricated, tested, and initially type classified.

Health hazard: An existing or likely condition, inherent to the use of materiel, that can cause death, injury, acute or chronic illness, disability, and/or reduced job performance of personnel.

Health hazard assessment (HHA): The process of identifying, evaluating, and controlling risks to the health and effectiveness of personnel who test, use, service, or support Army systems.

Health hazard assessment report (HHAR): The formal report documenting, for a given system, the assessment of health hazard issues and risks, recommended actions, and training requirements.

Health standards: Published documents specifying conditions of acceptable risk for individual health hazards; these can include medical exposure limits, health conservation criteria, and materiel design standards.

Human factors engineering (HFE): A comprehensive technical effort to integrate all personnel characteristics (skills, training implications, behavioral reactions, performance, anthropometric characteristics, and biomedical factors) into Army doctrine and systems.

Independent medical assessor: Personnel, independent of materiel developers and combat developers, normally tasked by the Army Medical Department to provide health hazard assessment support of Army materiel systems.

Life cycle system management model (LCSMM): An integrated model of phases, activities, documentation, and decision points guiding the acquisition of Army materiel.

Manpower and personnel integration (MANPRINT): The comprehensive process of integrating the full range of human factors engineering, manpower, personnel, training, health hazard assessment, and system safety throughout the entire materiel acquisition process.

MANPRINT Joint Working Group (MJWG): A multiagency group constituted to manage and integrate MANPRINT activities for a given materiel system.

Man-system integration: The technical process of integrating the human operator with a materiel system to ensure safe, effective operability and supportability.

Materiel acquisition: The process of acquiring supplies and equipment, facilities and services; includes life cycle systems management of hardware and software, formulation of requirements, research, development, testing, procurement, production, fielding, operation, support, and disposal.

Materiel acquisition decision process (MADP): The formal process for reviewing a program or project at critical points to evaluate status and make recommendations to the decision authority.

Materiel developer (MATDEV): Command or organization responsible for developing or modifying materiel.

Production/deployment: Normally the fourth phase in the materiel acquisition process. Involves procurement and distribution of equipment, training of operational units, and logistical support.

Requirements document: A document establishing officially the requirement for a specific materiel system and authorizing planning, budgeting, and execution. An informal requirements document (normally the Operational and Organizational Plan) usually authorizes program initiation. A formal requirements document (normally the Required Operational Capability) commits the Army to program development and describes the

system's required operational features and performance characteristics.

Risk assessment code (RAC): A quantitative expression of level of risk, formulated on the basis of hazard severity and hazard probability.

System MANPRINT management plan (SMMP): A planning and management guide used to ensure MANPRINT issues are addressed throughout a system's life cycle; also provides an audit trail.

System safety engineering: The application of system safety management and engineering principles throughout a system's life cycle.

Appendix A

Inventory of systems health hazards

A health hazard is some health-threatening condition which troops encounter in using materiel. The hazard can occur during normal use of equipment, interactions with environmental factors, maintenance and repair activities, logistics support functions, misuse, and malfunction. This appendix inventories the more frequently encountered health hazards and where they occur commonly in Army systems. The inventory is structured around five major categories: mechanical forces, chemical substances, biological substances, radiation energy, and environmental extremes.

Mechanical forces

Among Army systems, the mechanical forces which can injure personnel include acoustical energy (noise), vibration, shock, and trauma. That these hazards tend to occur together is not surprising, since they go hand in hand with engines, drive trains, tracks and wheels, transmissions, rotors, guns/cannons, and munitions--components of Army vehicles or aircraft. Outlined here are the basic forms, generic sources, and common system/component sources of each type of mechanical force.

Noise, steady state: intermittent, sustained, narrow band, wide band. Arises from generating, transmitting, and converting power; drive elements interacting with ground or air; electronic reproduction or amplification of sound; gas or fluid flow/friction; steady combustion. System source examples: tracked vehicles, wheeled vehicles, self-propelled artillery; aircraft (rotary- and fixed-wing); communication headsets and speakers; alerting or warning signals; power generators; training simulators; maintenance tools and equipment; gas torches; and compressed air/gas.

Noise, impulse: blast, impact, repetitive, nonrepetitive. Arises from propellant combustion; detonation of explosives; sudden release of pressure; forceful impact. System source examples: pistols, machine guns; grenades; mortars, cannons, tank guns, howitzers; recoilless rifles, rockets, missiles; nuclear warheads; explosives; training simulators; impact tools and equipment.

Blast overpressure: freefield, complex (reverberant), repetitive, nonrepetitive. Arises from propellant combustion and detonation of explosives. System source examples: mortars, cannons, tank guns, howitzers; recoilless rifles, rockets, missiles, explosives, nuclear warheads.

Vibration: high frequency, low frequency, linear, rotational, intermittent, sustained. Arises from generating, transmitting, and converting power; drive elements interacting with ground or air; resonance dynamics; induced changes or oscillations in system attitude or position. System source examples: tracked vehicles, wheeled vehicles, self-propelled artillery; aircraft (rotary- and fixed-wing); training simulators; maintenance tools and equipment.

Shock: acceleration, deceleration, force loading. Arises from system impact (crash, collision, hard landing); system recoil; sudden aircraft displacement due to air turbulence; windblast; parachute opening. System source examples: aircraft (rotary- and fixed-wing); wheeled vehicles, tracked vehicles, self-propelled artillery; parachute systems.

Trauma: blunt, sharp, musculoskeletal. Arises from objects or components impacting soldier; weapons blast; weapons recoil; shattering of components or materials; limb or head flail due to vehicle/terrain interaction; airblast; musculoskeletal overload. System source examples: tracked vehicles, wheeled vehicles; artillery (towed, self-propelled); tank guns; aircraft (rotary- and fixed-wing); hand-held guns, shoulder fired rockets/missiles; maintenance tools and equipment; compressed air/gas; explosive training devices; excessive operator force/exertion.

Chemical substances

Usually thought of as toxic substances, these are among the most pervasive health hazards. Chemically active compounds enter the picture frequently in basic system construction (e.g., paints, sealants, adhesives), routine operations and logistical support (e.g., fuels, coolants), maintenance (e.g., solvents, cleaning agents), and special functions (e.g., fire/flame suppression, decontamination). Contrasting with these is another family of substances generated by normal system operations, usually byproducts of engine combustion and weapons combustion. Of course, the specific fuels and propellants used will influence the byproducts encountered, as will a host of other factors. The basic forms in which primary substances and byproducts occur--liquids, gases, and solids--will guide the following summaries.

Liquids: including mists, aerosols. Associated with fueling, maintaining, and repairing systems; systems salvage and disposal; pest and plant control; decontamination; generation of obscurants; sewage handling and treatment. Common types include fuels, lubricants, coolants, hydraulic fluids, solvents, cleaning agents, paints, adhesives, pesticides, herbicides, defoliants, decontamination solutions. System source examples: systems incorporating combustion engines (piston, turbine), hydraulics,

air conditioners; systems for handling, storing, and transporting fuels and other petroleum products; maintenance shop; paint shop; repair shop; sewage handling and treatment systems; systems for handling, storing, transporting, and dispensing pesticides, herbicides, and defoliants; decontamination systems; fog oil generators.

Gases and vapors: Arise from vaporization of liquids or solids; engine combustion; weapons combustion; compressed gas; air filtration; electric motors; welding; flame/fire suppression. System source examples: systems incorporating combustion engines (piston, turbine), hydraulics, air conditioners; systems for handling, storing, and transporting fuels and other petroleum products; maintenance shop; paint shop; repair shop; gas torches; machine guns, tank guns, cannons, mortars, howitzers, recoilless rifles, rockets, missiles; gaseous fire suppression systems (e.g., Halon); systems for handling, storing, transporting, and dispensing liquid pesticides, herbicides, and defoliants; sewage handling and treatment systems; compressed gas systems and containers; liquid decontamination systems; protective filters.

Solids: coatings, aerosols, fumes, dusts, particulates. Arise from system-environment interaction; burning materials; generation of smokes/obscurants; construction activities; blasting; welding, brazing, soldering; cutting, grinding, and sanding of metals, plastics, wood; decontamination; pest and plant control; air filtration. System source examples: tracked vehicles; wheeled vehicles; aircraft (rotary- and fixed-wing); artillery (towed, self-propelled); munitions; explosives; smoke/obscurant systems; construction equipment; maintenance shop; paint shop; repair shop; power saws, grinders, sanders; welding, brazing, and soldering equipment; powder-form decontamination systems; systems for handling, storing, transporting, and dispensing pesticide and herbicide dusts; protective filters.

Biological substances

This category arises mainly from contamination or infiltration of systems by disease-causing microorganisms which reside in the earth's environment. Common types include bacteria, viruses, parasites, Rickettsia, molds, and fungi. These organisms may grow (or at least survive) wherever there is a "reservoir" containing a hospitable medium, such as water or nutrified liquid. System reservoir examples: containers, tanks, lines, tubes, compartments, and receptacles where a hospitable liquid may occur, collect, or circulate; systems for processing, handling, storing, transporting, preparing, and dispensing foodstuffs (both solid and liquid form) and water; medical supplies and biologicals; waste disposal equipment; sanitation systems; sewage handling and treatment systems.

Radiation energy

The common types of radiation which accompany Army systems include visible light, infrared, ultraviolet, radiofrequency energy, laser energy, and ionizing radiation. Systems or subsystems designed for special functions, especially of an electrical or electronic nature, most frequently give rise to these types of energy. The sections below summarize the basic forms and generic sources of each type of radiation.

Radiofrequency energy: microwaves, millimeter waves, transient, sustained. Generic sources: telecommunications systems, radar systems, microwave ovens.

Infrared: sustained, transient. Generic sources: heating elements (such as those used in food preparation equipment and space heaters), gas torches, soldering equipment, electronic repair equipment.

Visible light, high intensity: artificial, natural, transient, sustained. Generic sources: search lights, landing lights, strobes, high-intensity lamps, light amplification devices, cathode ray tubes, natural sunlight, highly reflective surfaces, laser reflection, gas torches, nuclear flash.

Ultraviolet: near UV, far UV, artificial, natural, transient, sustained. Generic sources: ultraviolet lamps, gas torches, gas discharge tubes, natural sunlight (varies with season, altitude, etc.).

Laser energy: pulsed, transient, sustained. Generic sources: rangefinders, target designators, training simulators, sensor-targeted countermeasure systems, material processing systems.

Ionizing radiation: transient, sustained. Generic sources: high-voltage electronics, X-ray equipment, radioluminescent materials, nuclear weapons, depleted uranium munitions.

Environmental extremes

On the training range and the battlefield, environmental factors such as temperature, humidity, wind, and altitude obviously interact with combat systems and their operators. In their extreme forms and combinations, these factors may threaten the soldier's health. In the case of Army materiel, we are concerned with three categories of environmental extremes--ambient heat, ambient cold, and oxygen deficiency.

Ambient heat: convective, radiant, natural, artificial,

transient, sustained. Arises from environmental heat, sunlight; heat-generating systems and subsystems; human metabolism. System source examples: tracked vehicles, wheeled vehicles; self-propelled artillery; aircraft (rotary- and fixed-wing); cannons, guns, rockets, missiles (as components of systems with enclosed crew compartments); training simulators; collective shelters; protective clothing, helmets, masks, respirators, gloves, boots; food preparation equipment; heaters; lamps; electrical/electronic equipment. Contributing factors: humidity, wind, clothing, workload.

Ambient cold: natural, artificial, transient, sustained. Arises from environmental cold, ice; cooling subsystems. System source examples: tracked vehicles, wheeled vehicles; self-propelled artillery; aircraft (rotary- and fixed-wing); systems/subsystems for air conditioning, refrigeration, and frozen storage; training simulators; collective shelters. Contributing factors: humidity, moisture, wind, clothing, workload.

Oxygen deficiency: natural, artificial, transient, sustained. Arises from high altitude (terrestrial, airborne); oxygen displacement in confined spaces; systems which constrain breathing. System source examples: aircraft (fixed- and rotary-wing); airborne operations; high altitude operations; altitude chamber; gaseous fire suppression systems; protective masks, respirators. Contributing factors: workload, ambient temperature, engine combustion fumes, weapons combustion fumes, fuel vapors.

Appendix B

Integrated life cycle system management model

Source: Adapted from AR 70-1

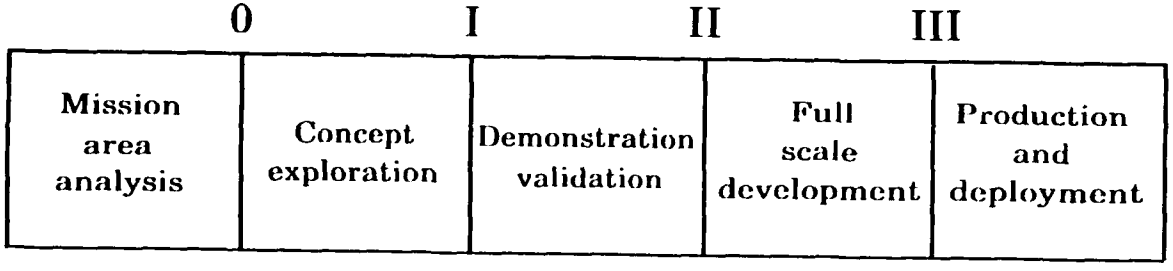

Figure B-1. Schematic showing the sequential phases involved in developing Army materiel.

Life cycle system management model

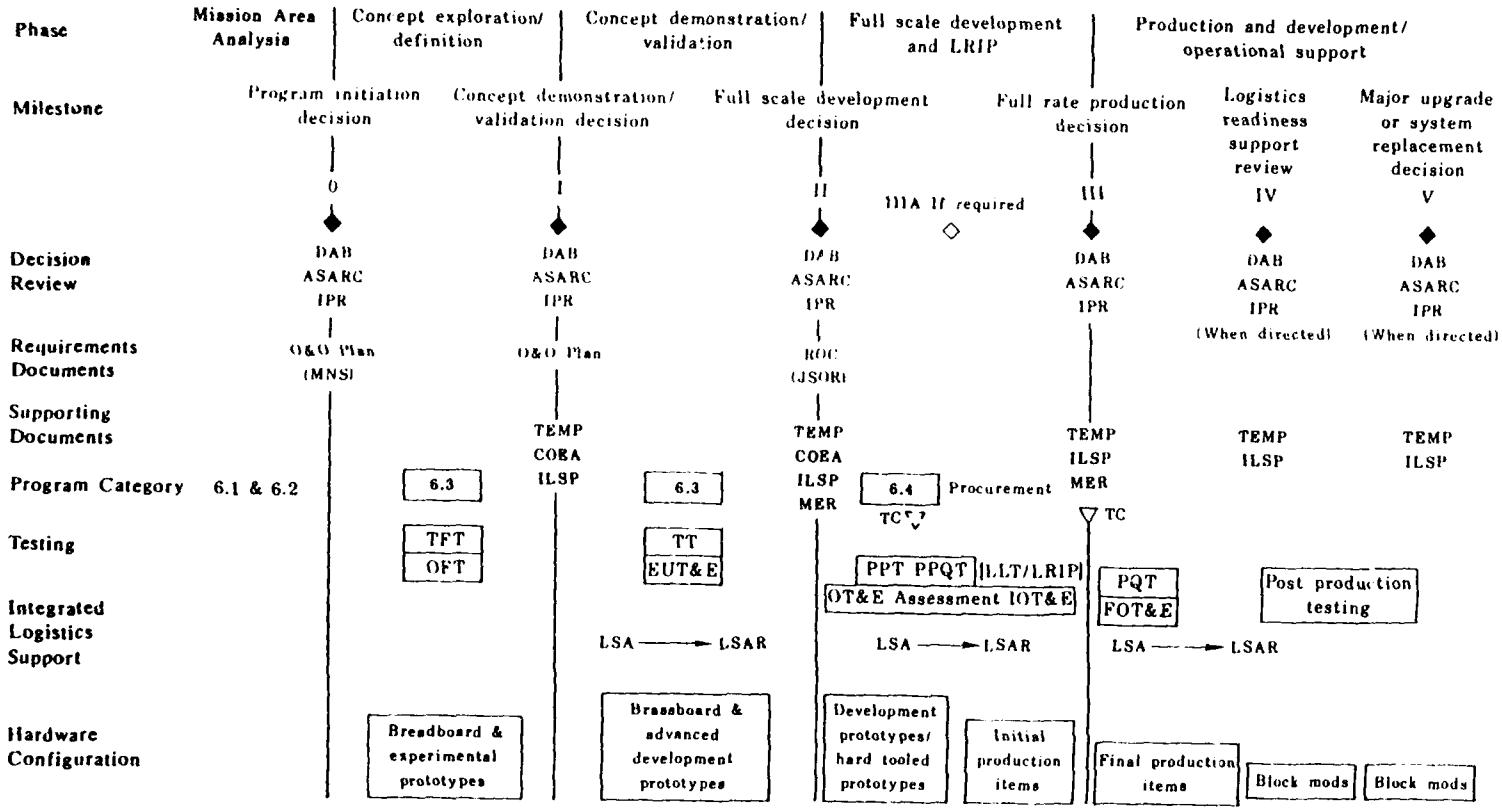

Figure B-2. Phase-by-phase depiction of the salient features of the management model which guides development of Army systems.

Appendix C

List of HHA points of contact

OTSG:	HQDA (SGPS-PSP-E)	AV	289-0129
	5109 Leesburg Pike Falls Church, VA 22041-3258	(202)	756-0129
AHS:	Commandant Academy of Health Sciences, US Army ATTN: HSHA-CDM Fort Sam Houston, TX 78234-6100	AV (512)	471-5775 221-5775
AEHA:	Commander US Army Environmental Hygiene Agency ATTN: HSHB-MO-A Aberdeen Proving Ground, MD 21010-5422	AV (301)	584-2925 671-2925
MRDC:	Commander US Army Medical Research and Development Command ATTN: SGRD-PLC Fort Detrick Frederick, MD 21701-5012	AV (301)	343-7301 663-7301
AMC:	Commander US Army Materiel Command ATTN: AMCSG 5001 Eisenhower Avenue Alexandria, VA 22333-0001	AV (202)	284-8975 274-8975
TRADOC:	Commander US Army Training and Doctrine Command ATTN: ATMD Fort Monroe, VA 23651-5000	AV (804)	680-2226 727-2226

Appendix D

Risk assessment codes

Source: AR 40-10

Table D-1. Hazard probability

Descriptor	Level	Specific individual item	Fleet or inventory
Frequent	A	Likely to occur frequently	Continuously experienced
Probable	B	Will occur several times in life of an item	Will occur frequently
Occasional	C	Likely to occur sometime in life of an item	Will occur several times
Remote	D	Unlikely but possible to occur in life of an item	Unlikely but can reasonably be expected to occur
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced	Unlikely to occur, but possible

Table D-2. Risk assessment codes

Hazard severity categories	Hazard probability levels				
	A	B	C	D	E
I	1	1	1	2	3
II	1	1	2	3	4
III	2	3	3	4	5
IV	4	5	5	5	5

Appendix E

Acronyms

AEHA	U.S. Army Environmental Hygiene Agency
AHS	Academy of Health Sciences, U.S. Army
AMC	U.S. Army Materiel Command
AMEDD	Army Medical Department
AR	Army regulation
ASARC	Army Systems Acquisition Review Council
BOP	blast overpressure
COEA	cost and operational effectiveness analysis
CRDEC	U.S. Army Chemical Research, Development, and Engineering Center
CBTDEV	combat developer
CSTA	Combat Systems Test Activity
DAB	Defense Acquisition Board
DCSPER	Deputy Chief of Staff for Personnel
ECP	engineering change proposal
EUT&E	early user test and evaluation
FOTE	follow-on operational test and evaluation
HEL	U.S. Army Human Engineering Laboratory
HFEA	human factors engineering assessment
HHA	Health Hazard Assessment
HHAR	Health Hazard Assessment Report
HSC	U.S. ArmyHealth Services Command
IHHAR	Initial Health Hazard Assessment Report
ILSP	integrated logistics support plan
IOTE	initial operational test and evaluation
IPR	in-process review
JSOR	Joint Services Operational Requirement
LAIR	Letterman Army Institute of Research
LLT	long lead time
LRIP	low rate initial production
LSA	logistic support analysis
LSAR	logistic support analysis record
MANPRINT	Manpower and Personnel Integration
MATDEV	materiel developer
MEDCEN	Medical Centers
MEDDAC	Medical Department Activities
MER	manpower estimate report
MJWG	MANPRINT Joint Working Group
MNS	mission need statement
MRDC	U.S. Army Medical Research and Development Command
NBC	nuclear, biological, chemical
NRDEC	U.S. Army Natick Research, Development, and Engineering Center
ODCSPER	Office of the Deputy Chief of Staff for Personnel

OFT ..... operational feasibility testing
O&O Plan ..... Operational and Organizational Plan
OT&E ..... operational test and evaluation
OTEA ..... Operational Test and Evaluation Agency
OTSG ..... Office of The Surgeon General
PEO ..... program executive officer
PM ..... project/product manager
PPT .... production proveout test
PPQT ..... preproduction qualification test
PQT ..... production qualification test
RAC ..... risk assessment code
RFP ..... Request for Proposal
ROC ..... Required Operational Capability
SAR ..... safety assessment report
SMMP ..... System MANPRINT Management Plan
SSPP ..... System Safety Program Plan
TC ..... type classification
TDR ..... Training Device Requirement
T&E ..... test and evaluation
TECOM ..... U.S. Army Test and Evaluation Command
TEMP ..... test and evaluation master plan
TFT ..... technical feasibility testing
TNGDEV ..... training developer
TRADOC ..... U.S. Army Training and Doctrine Command
TSG ..... The Surgeon General
TT ..... technical testing
USAARL ..... U.S. Army Aeromedical Research Laboratory
USAMMDA ..... U.S. Army Medical Materiel Development Activity
USABRDL ..... U.S. Army Biomedical Research and Development Laboratory
USARIEM ..... U.S. Army Research Institute of Environmental Medicine
WRAIR ..... Walter Reed Army Institute of Research

Appendix F

List of suggested readings

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